WIRELESS SENSOR NETWORKS: COMPARATIVE STUDY AND ANALYSIS OF MAC PROTOCOLS

UMESH KUMAR SINGH, KAILASH CHANDRA PHULERIYA & RAKHI SUNHARE

Department of Computer Science, Institute of Computer Science, Vikram University,

Ujjain, Madhya Pradesh, India

ABSTRACT

Wireless Sensor Network (WSNs) communication has become the most exciting area in communications and networking. A larger number of WSNs applications require reliable data delivery in real time. The use of WSNs is increasing day by day and at the same time it faces the problems of low processing power of the nodes and high energy consumption but reliable data delivery in the real time also needs proper attention. The aim of the paper is to study different Medium Access Control protocols (MAC) for WSNs. Now we select important MAC protocols and check the performance of these protocols using simulator software and to motivate the researcher, while showing the future aspects in the area of WSNs.

KEYWORDS: Wireless Sensor Network, Medium Access Control, Reliability, Real Time, Simulation

1. INTRODUCTION

A wireless sensor networks (WSNs) consists a lot of sensing devices deployed in a given environmental area for collaboratively gathering/sensing specific information. The main part of WSNs is sensing device which is called sensor node. A sensor field can be considered as the area in which the nodes are placed. The nodes are low-cost and portable devices with limited processing power and energy resources. Sensor nodes can be used to collect information from the environment and process this data locally then transmit back to the user. The sensing devices are low power devices including microcontroller, microchip and antenna. Figure 1 shows the typical wireless sensor network that consist of multiple number of sensor nodes and 3-sink node where data is collected are deployed in the sensing field.
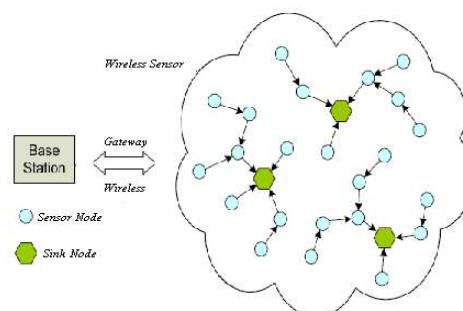

Figure 1: Wireless Sensor Networks [1]

Many WSNs applications require reliable data transport such as biological monitoring, health care monitoring, and battlefield surveillance these also require high end-to-end reliability. WSNs have led to many new protocols specifically designed for different kinds of applications and most of the attention has been focuses to the Medium Access Control (MAC) layer protocols. The MAC layer is a sub-layer of the data-link layer and it provides efficient usage of the

communication channel so that nodes can access the channel without collision. It helps the node to access the channel for data transmission. The MAC protocol plays an important role in energy saving throughput, Quality of Service (QoS) and minimum delay. A reliable Protocol in wireless sensor networks is a protocol that can reliably deliver packets from their sources to their destinations without packet loss.

Many WSNs Applications require that a message or an operating action should be transmitted within a fixed time span, or even processed within a fixed middle time frame [2-6]. If a communication system meets the time requirements of such an application, this system is referred to as being real-time capable. A requirement for real-time capability is that a communication applicant is able to start his data transmission within an approved maximum time. This can only be guaranteed when access rights are granted in a definite order. Most of the MAC protocol shows better and efficient features for real time applications but there are still many more challenges that need to be solved [7, 8].

In [9, 10] Singh, Phuleriya et al, addressed that there is still need to find out the suitable solution for real time support and energy efficiency because Contention-based MAC Protocols are energy efficient but they don't guarantee the real time support while Scheduled-based MAC Protocols give real time support but quite weak in energy saving. The design of real time support and energy efficient protocols in WSNs will be a challenging and interesting area of young researcher. We claimed that nowadays no such protocol that honestly supports both the reliability and energy efficient in real time communication. Present state of art shows that study about MAC protocols including the issues reliability and energy efficiency is more fruitful for research and technological development.

In this paper we organized in the following section: In section 1, we first introduces about Wireless Sensor Networks. In section 2, we introduces about MAC Protocols and Reliable Data Delivery in Real Time. In section 3, we describe the Major issues in MAC protocols are reliable delivery of data and energy efficiency. In this section we briefly described the reliability and energy efficiency issues. Performance matrices for MAC protocols are also described here for best suitable protocol. In section 4, we describe the performance matrices of MAC protocols. In section 5, we compare the performance of S-MAC and Flexi-MAC protocols using network simulator. In finally we devoted to the overall conclusions of this paper and future work.

2. MAC PROTOCOLS & RELIABLE DATA DELIVERY IN REAL TIME

MAC is an important technique that ensures the successful operation of the network. One of the main functions of the MAC protocol is to avoid collisions from interfering sensor nodes. The Sensor Nodes is a heart of WSNs. The main task of a sensor node is to identify events, perform quick local data processing and then transmit the data to a specific sink. It is divided into three domains: sensing, processing and data communication. Several factors responsible to energy waste, including excessive overhead, idle listening, packet collisions and overhearing. Retransmission of colliding packets is a significant source of energy waste among all these factors.

MAC layer protocols play a key function in determining channel utilization, network delay and more important power consumption. The main objective in most of the MAC layer protocols is to reduce energy waste caused by collisions, idle listening, overhearing, and excessive overhead to increases the network lifetime.

The basic requirement of a sensor network is reliable data delivery in real time. It is an important topic in wireless sensor networks. Real-time data communication is the communication in which information is received at or nearly at the moment it is sent. Real-time applications demand the concept of QoS, in which there may be a scale of performance that is

acceptable, and the boundary between success and failure of the system may be blurred or varied. In wireless sensor network there are several types of reliable protocols for reliable communication. A reliable protocol in wireless sensor networks is a protocol that can reliably deliver packets from their sources to their destinations without packet loss. Most of the WSNs applications require reliable data delivery in real time. For example, consider a sensor network deployed in a chemical plant to detect harmful gas. It is crucial for sensor nodes to reliably transport every sensor reading back to the sink. Other critical WSN applications such as biological monitoring, health care monitoring, and battlefield surveillance also require high end-to-end reliability [11].

3. RELIABLE AND ENERGY EFFICIENT MAC PROTOCOL DESIGN ISSUES

Now, we have introduced the aspects of real time data delivery and energy consumption for wireless sensor networks. The six aspects of wireless communication can be specified which are mainly responsible for the limitation of the lifetime and the performance of the sensor nodes. In the following, these communication aspects are discussed in detail.

3.1 Idle Listening: Idle listening represents the most noticeable way to waste energy. The term Idle listening Node keeps in idle state to sense the idle channel, waiting for potential traffic. This state is costly in case of low network loads, because there are many transceivers still consume significant energy in idle state.

3.2 Overhearing: Wireless medium is a broadcast medium. All neighbors can receive the packets in the channel, even if the packets are not towards them. This situation is called overhearing problem. Overhearing often occurs when a large number of nodes transmit their sensed values at the same time. There are three strategies which are mostly followed by MAC protocols to provide real time communication and reduce the energy waste caused by overhearing. One possibility is to (locally) aggregate the data traffic [12-15] in order to avoid the forwarding of unnecessary information.

3.3 Collision: Collisions stand for the worst-case for communication in WSNs since packets may have to be retransmitted over several hops which increase the energy consumption and the utilization of the medium. Collision also leads packets discard and retransmission. Destination node wastes energy for receiving, on the other hand, source node wastes energy for sending. Although retransmission can recovery some packets, it increases end-to-end delay and wastes extra energy for more control packets. This behavior can lead to a total collapse of the network [16] due to the increased traffic load.

3.4 Protocol Overhead: Protocol overhead is also called control packet overhead. If source node and its destination nodes exchange too many control packets, the traffic load will increase and waste energy in transmitting and receiving. The amount of protocol overhead is often larger in WSNs than the application data, due to the small payload that is transmitted by the sensor nodes. A popular strategy to minimize the protocol overhead is to (locally) aggregate the data [17] before a packet is transmitted in order to reduce the number of required MAC headers.

3.5 Traffic Variation: Traffic variation outcome from the event-based communication model in WSNs. Packet loads are the effect of the highly correlated traffic which drives the network into temporary congestion. The high number of competing nodes may lead to packet loss or very high delay depending on the used contention resolution mechanism. The usage of a long contention window only disseminates the traffic load to some extend due to the fact that the delay of packets is increased. As a consequence of the additional delay, the MAC protocol may trigger retransmissions which further increase the traffic load and the delay such that even more retransmissions are triggered.

3.6 Over-Emitting: Over-emitting represents another aspect of wireless communication which reduces the rate of real time data delivery and increases the energy consumption in WSNs. It describes the event when a node is transmitting a packet to another node which is currently not listening to the radio channel. The impact of over-emitting scales with the node density in the network. However, over-emitting may reduce the lifetime of a WSN in a significant way if the MAC protocol is based on wake-up functions. A large number of MAC protocols use preambles or busy signals to indicate a future data transmission. Over-emitting can be reduced by synchronizing the nodes in the network [18].

3.7 Channel Error: If the channel error is high, then the packets received at the physical layer may be corrupted requiring retransmission of the packet. This can be done by using positive (or negative) acknowledgements for each successful (or unsuccessful) reception or sending multiple copies of the same packet on the same or multiple routes.

4. PERFORMANCE MATRICES OF MAC PROTOCOLS

The research community considers the following matrices in order to evaluate and compare the performance of energy conscious MAC protocols. This is mandatory for protocols in order to provide best support on real time application looking on to the great requirement of such protocols. In order to check the performance of the designed protocol we have given a matrix which is as follows.

- **Energy Consumption per Bit:** The energy efficiency of the sensor nodes can be defined as the total energy consumed total bits transmitted. The unit of energy efficiency is joules/bit. The lesser the number, the better is the efficiency of a protocol in transmitting the information in the network. This performance matrices gets affected by all the major sources of energy waste in wireless sensor network such as idle listening, collisions, control packet overhead and overhearing.

- **Average Delivery Ratio:** The average packet delivery ratio is the number of packets received to the number of packets sent averaged overall the nodes.

- **Average Packet Latency:** The average packet latency is the average time taken by the packets to reach to the sink node.

- **Network Throughput:** The network throughput is defined as the total number of packets delivered at the sink node per time unit.

- **Network Lifetime:** Network lifetime measures the time until the first node in the network dies. The usefulness of the sensor network depends on the availability of sufficiently large number of sensors to cover the area of interest; therefore, prolonging the lifetime of a sensor node is important.

The following metrics are used for evaluating end-to-end guarantees on data delivery:

Packet latency measures the total time required for a packet to reach the sink node since it is sent by a source node. Error rate measures the number of transmission errors (collisions due to radio interference) over the total number of transmissions. Network throughput measures the total number of data packets received at the sink node to the total number of packets sent. A high network throughput indicates a small error rate for packet transmission and a low level of contention for medium access. Fairness measures the total number of nodes in a network that can access the channel equally within a period of time.

5. COMPARATIVE RESULTS

A comparison of the aforementioned MAC protocols is shown in Table 1. This comparative study helps in identifying real time support and energy efficient MAC protocols.

Table 1: Comparison of MAC Protocols

Protocol	MAC type	Real Time Support	Energy efficiency	Scalability
S-MAC	CSMA/CA	Good	Moderate	Good
T-MAC	CSMA/CA	Moderate	high	Good
PMAC	CSMA/CA	Moderate	high	Good
DS-MAC	CSMA/CA	Moderate	high	Good
PS-MAC	CSMA/CA	HRT	Moderate	N/A
R-MAC	CSMA/CA	HRT	high	moderate
E2RMAC	CSMA-based	Good effort	high	Good
Flexi-MAC	TDMA based	Good effort(but used two radio)	Moderate	100%
DGRAM	contention-free TDMA-based	Good effort	moderate	Low
SPARE - MAC	TDMA based	Good effort	Moderate	Moderate
ER-MAC	TDMA based	Good effort	low	Good
RT-MAC	TDMA based	Good effort	moderate	Good

Table 1, contains and compares all the existing protocols and their characteristics with performances and describes their types and reliability in real time data delivery and energy efficiency. S-MAC protocol is working in moderate level with sufficient energy efficiency in real time data communication but the scalability of S-MAC protocol is good. T-MAC, P-MAC and DS-MAC protocols working in moderate range with sufficient energy efficiency although PS-MAC, RMAC protocols are working in HRT but their Scalability is under a moderate range. Flexi-Mac protocol shows the best scalability and energy efficiency but the real time data delivery is not too fine as compare to above P-MAC, S-MAC and RMAC protocols because it is used to require two radios for communication. The DGRAM, SPARE-MAC, ER-MAC and RT-MAC are good effort for real time communication but these protocols are not energy saver.

On the comparisons of above table 1 we select two protocols S-MAC and Flexi-MAC. Now we compare the S-MAC [19] and Flexi-MAC [20] protocols used origin software. The performance of S-MAC and Flexi-MAC are checked by Authors using network simulator-2 version2.29 [21] made by the LBNL (Lawrence Berkeley National Laboratory). Network simulator2 is a very reliable simulator that is suitable for verifying the efficiency of wireless sensor networks. Our simulation settings and parameters are summarized in following Table 2.

Table 2: Simulation Setting

Parameter	Value
Simulation time	700 sec
Bandwidth	250 kb/s
Packet Size	512byte
Transmit Power	0.350 W
Receiving Power	0.385 W
Idle Power	0.311 W
Initial Energy	5.0J
Fault Time	0.1, 0.2, 0.3, 0.4, 0.5

In the initial experiment, we vary the channel error rate as 0.01, 0.02, 0.03, 0.04 and 0.05, keeping the number of nodes as 50, number of flows as 4 and transmission rate as 100Kb. Following Figure 2 show the average end-to-end delay

for the Flexi-MAC and SMAC protocols. We can see that the average end-to-end delay of the Flexi-MAC protocol is less when compared to the SMAC. When the error rate is increased, the end-to-end delay tends to increase for both the schemes.
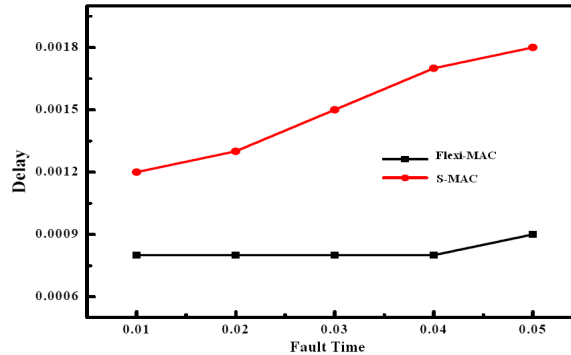

Figure 2: Difference of Delay with Respect to Fault Time

Figure 3 presents the packet delivery ratio of both the protocols. The packet delivery ratio gives the ratio between the numbers of packets sent to that received. It is already explained that, when error rate increases the number of packets successfully reaching the destination is less due to the large number of packet losses. Since the packet drop is less and the throughput is more, Flexi-MAC achieves good delivery ratio, compared with S-MAC protocol.
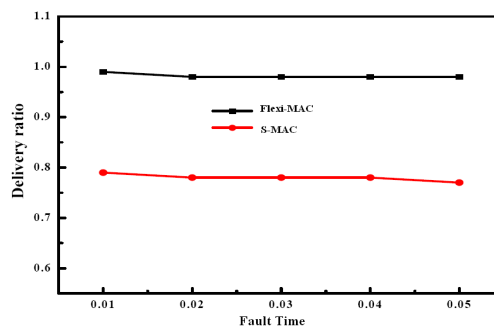

Figure 3: Difference of Delivery Ratio with Respect to Fault Time

Following figure 3 shows the Comparison of Flexi-MAC and S-MAC in terms of Average Consumed Power versus the achieved Throughput.
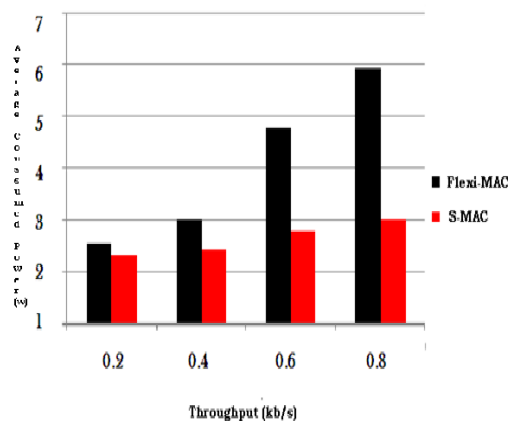

**Figure 4: Average Consumed Power versus the Achieved Throughput,
Comparison b/w Flexi-MAC and S-MAC**

From the above figure 4, it is clear that S-MAC is able to support a given throughput consuming much less power than compare to Flexi-MAC. The power consumptions increase linearly with respect to the achieved throughput in both cases.

6. CONCLUSIONS AND FUTURE SCOPE

WSNs are quite new field for young researchers. It is necessary in the present world as well as in security purpose and real time applications. The use of WSNs is increasing day by day and at the same time it faces the problems of low processing power of the nodes and high energy consumption but reliable data delivery in the real time also needs proper attention. Unfortunately there is no precise study carried out in this area. Some time critical applications require for reliable data delivery in real time and it is an important topic in WSNs. The commonly used TDMA based protocol gives real time support but they are not good for energy efficient for current requirement and upcoming challenges. CSMA/CA based MAC protocols are found to observed energy efficient but they don't assured about reliable data delivery. As the base of our comparative results the Flexi-MAC protocol performance are so good for reliability features in real time applications but not supportive simultaneously in both reliability and energy efficiency. On other hand S-MAC protocol are so good for energy saving features in real time applications but not supportive simultaneously in both reliability and energy efficiency. So in future we develop a new MAC protocols which solve the above mentioned problems efficiently.

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